Arctic sea-ice volume budget from satellite observations and CMIP6 models

The role of divergence

Harold Heorton, Michel Tsamados, EGU 2022

What is a sea ice volume budget?

Analysing the dynamic and thermodynamic changes in sea ice volume

Intensification
From concentration and thickness data.
Local rate in change in sea ice volume.

Divergence
From concentration, thickness and ice drift data.
Volume • local gradient in velocity

$$\frac{dV}{dt} = -\mathbf{u} \cdot \nabla V - V \nabla \cdot \mathbf{u} + \text{residual}$$

V: Sea ice volume

$\mathbf{u}$: Sea ice drift velocity

Advection
From concentration, thickness and ice drift data
Velocity • local gradient in volume

Residual
The part left unaccounted for.
This is from thermodynamics

We use this technique for daily CMIP6 model data, capturing the source and location of sea ice growth and melt.

Arctic Sea Ice Volume

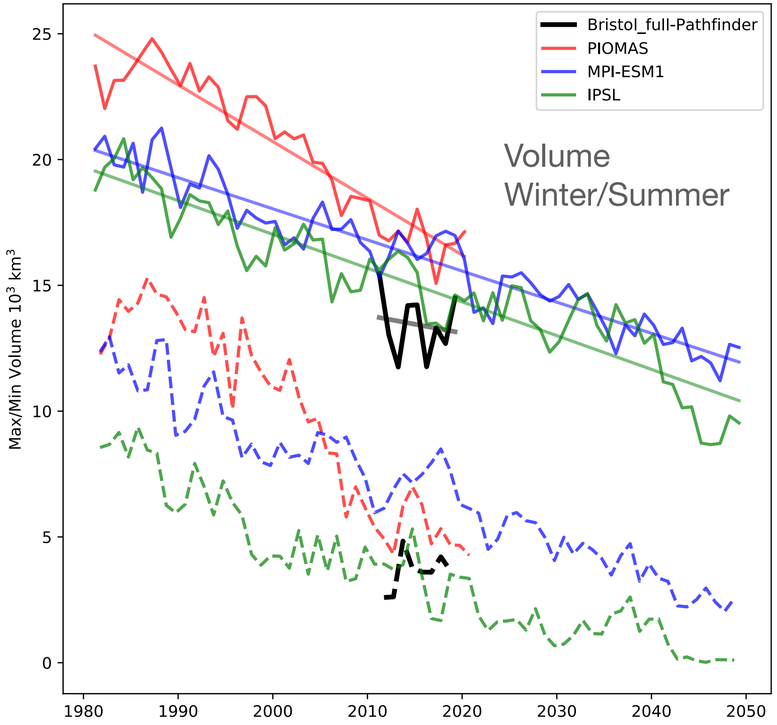
- Using results from two CMIP6 models:
  - IPSL and MPI-ESM1 (SSP585)

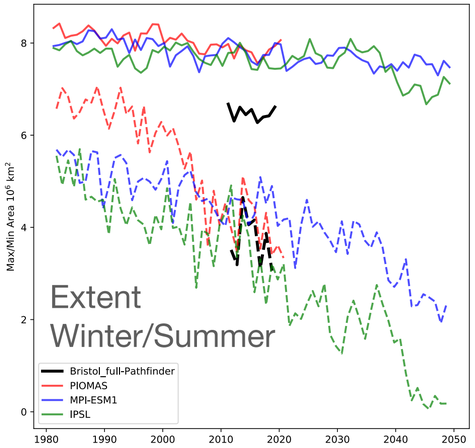
- These will be contrasted to PIOMAS, and also an observational budget using:
  - The new winter and summer Bristol sea ice thickness product
  - Pathfinder sea ice drift

- We use the same budget analysis equations for each. Looking at daily data.

- This allows for the analysis of terms not generally available from CMIP6 model runs (dynamic vs thermodynamic growth) and the flow through various gates in the Arctic Ocean.

- All models show a decrease in volume that can be fitted well with a linear trend. We use this linear approximation later

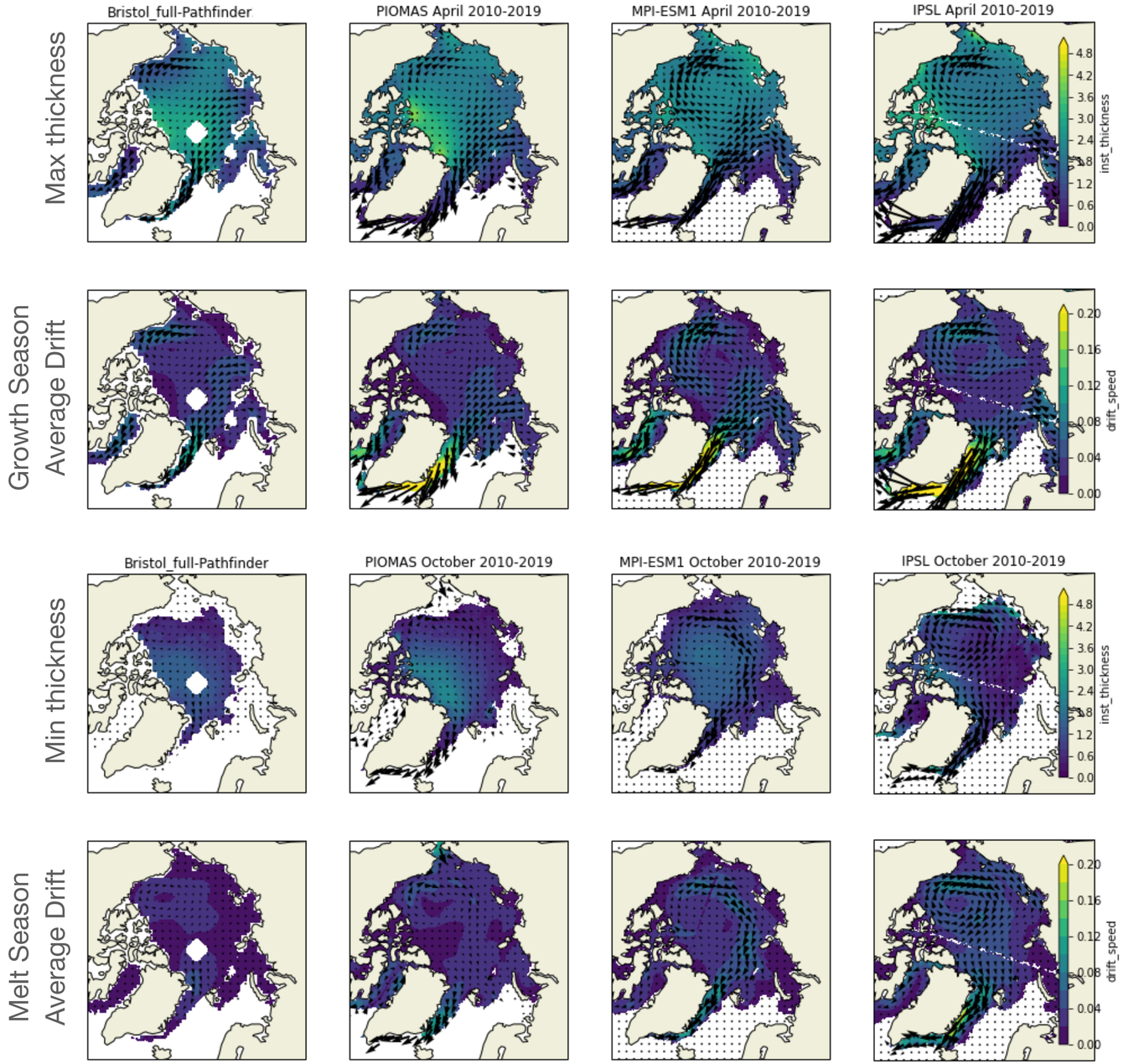




Maps of Budgets

Models vs observations

- Comparing all the models and the obsertvations over the CryoSat period, 2010 - 2019
- The thickness is well modelled
- All the models give a higher average drift speed than Pathfinder



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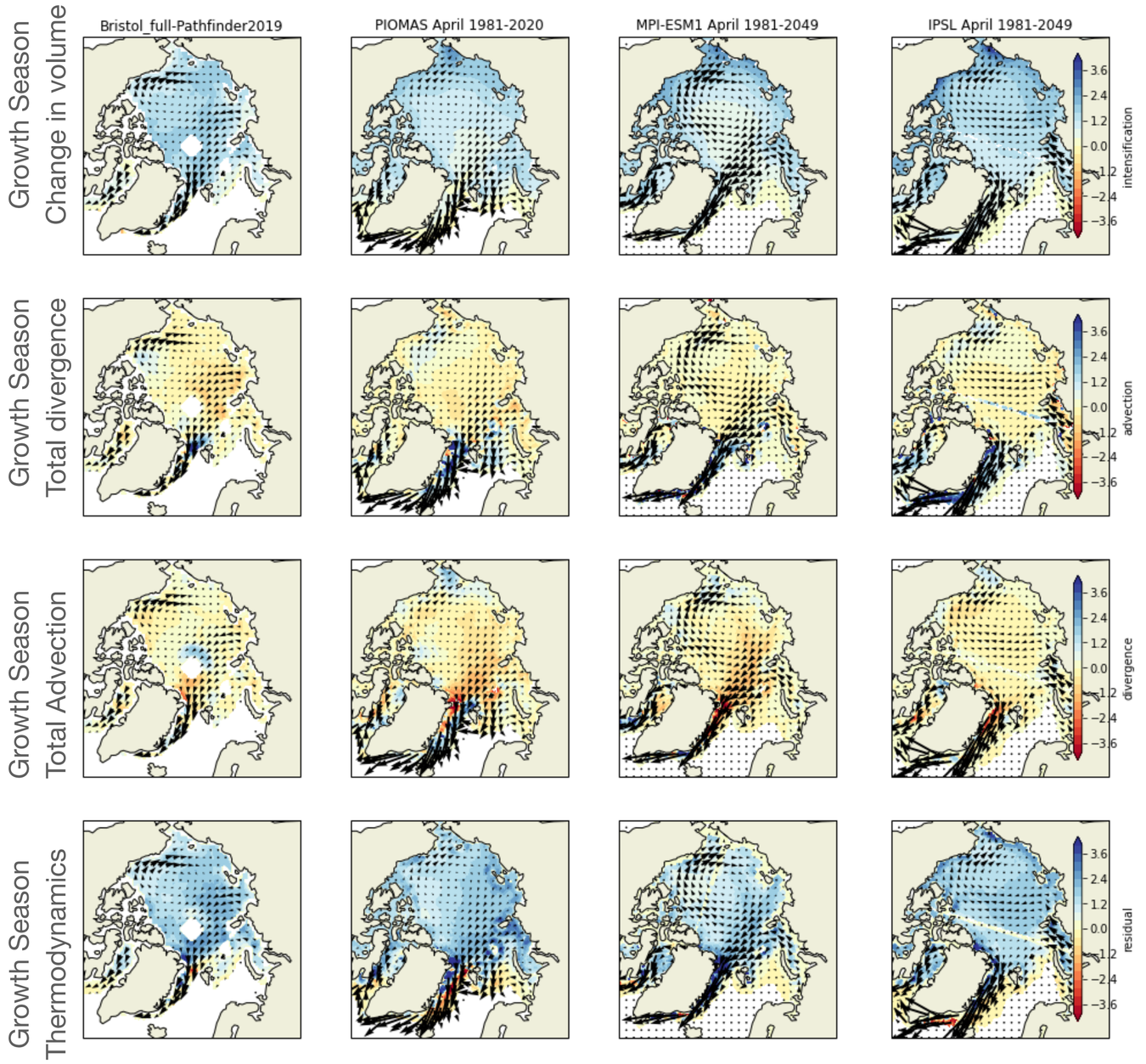
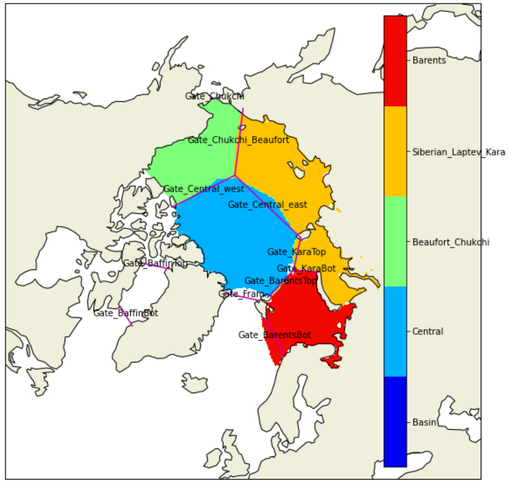


Seasonal cycle of sea ice volume

Fractions of max volume

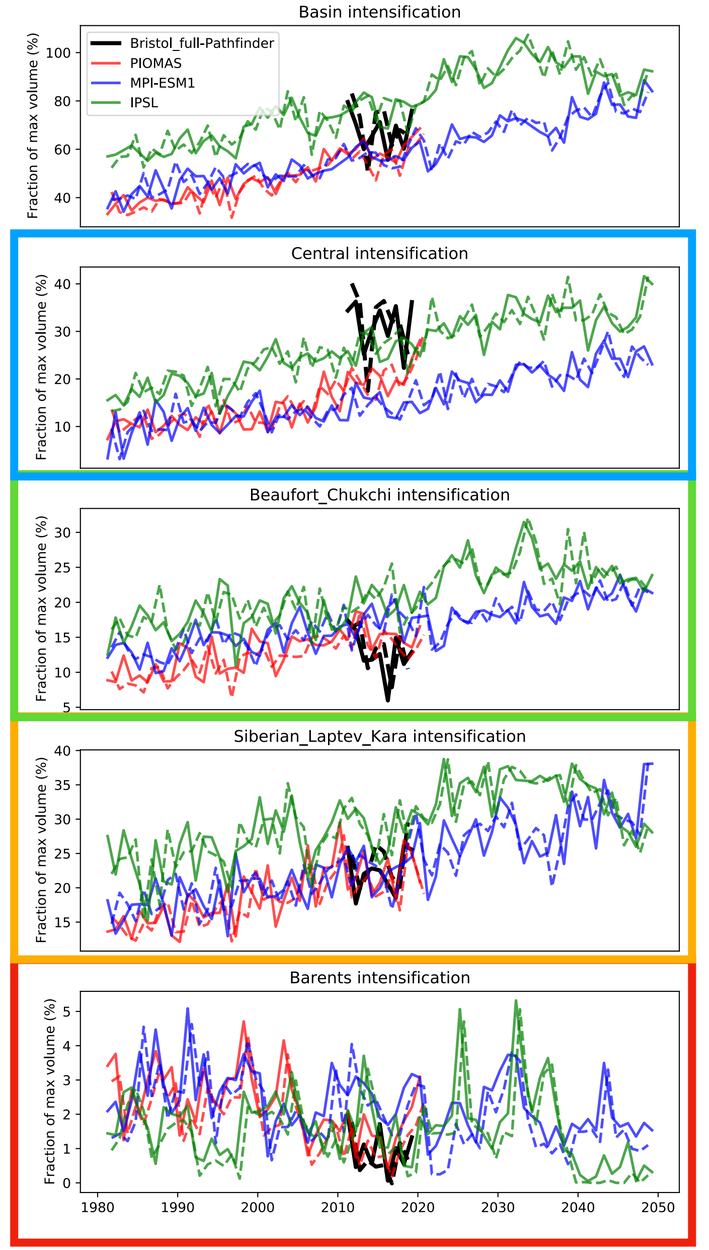
- Using the linear trends in sea ice volume we normalise the season change in volume (intensification), by the longer time scale change in volume.
- We plot the winter growth (solid lines), and summer melt (dashed lines)
- During the 1980s, the models predict that the seasonal cycle accounted for around 50% of the total sea ice volume
- This may increase to 100% by 2050 (ice free summer)



Seasonal Growth as a fraction of total volume

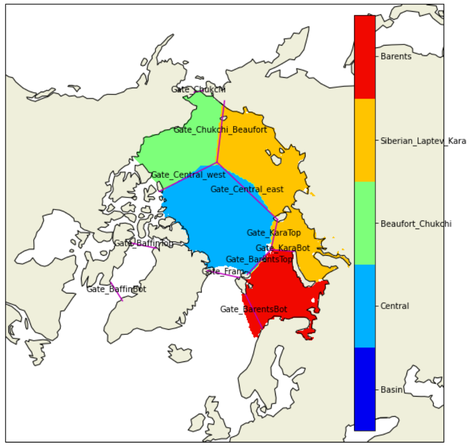
Total

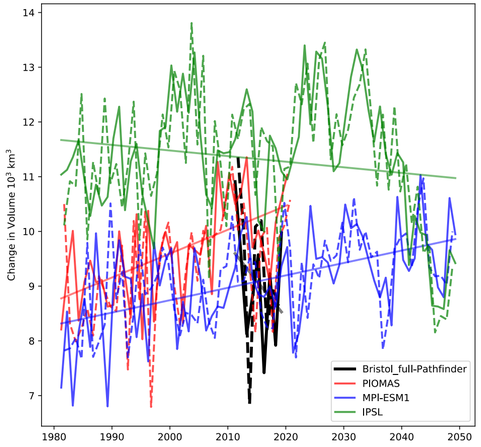
Regions



But where is the ice growing?

How much does thermodynamics contribute to the total seasonal cycle?

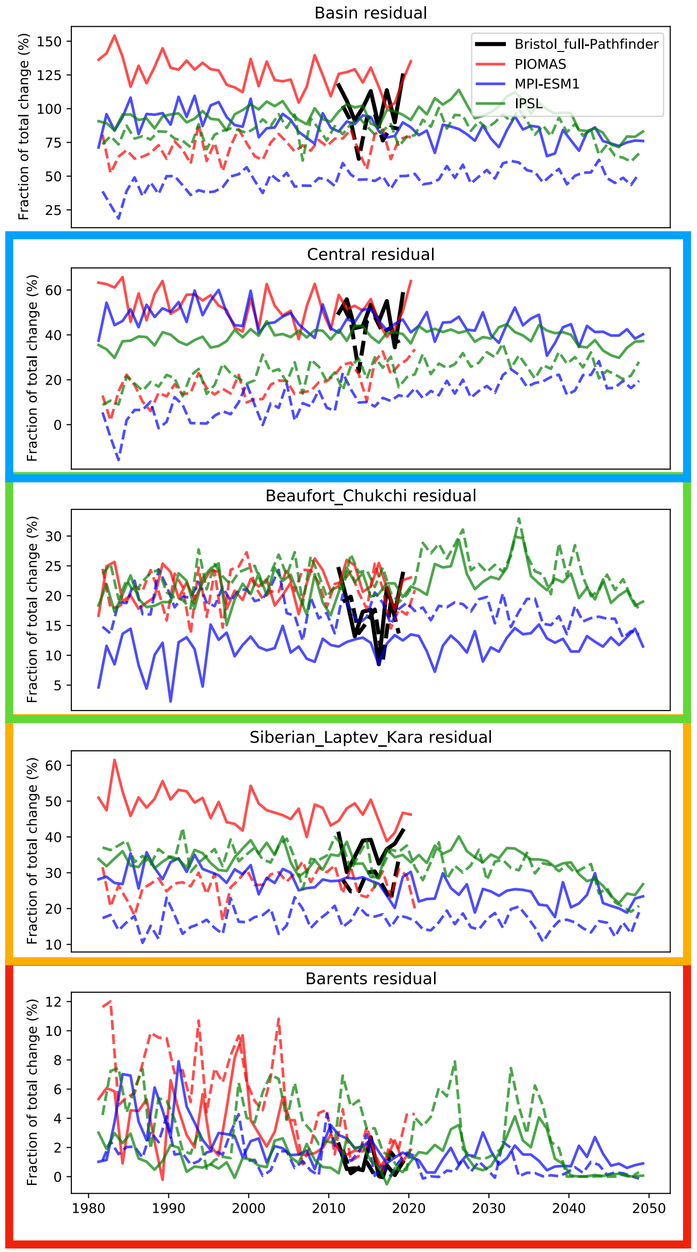




Season Cycle of sea ice volume

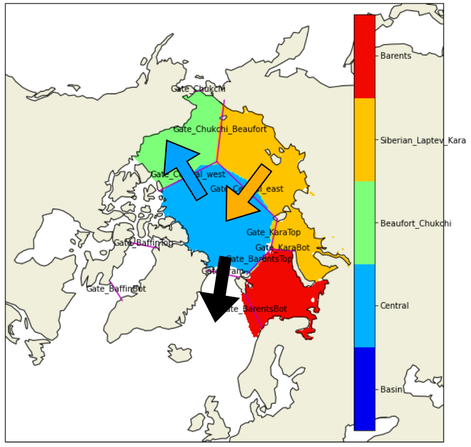
- In general the volume of sea ice grown the in Arctic basin is greater than which melts
- The Central region has 50% of the ice growth but only 20% of the melt
- There are significant volumes of sea ice lost in divergence and transportation to the north Atlantic
- There is a spread between the models. PIOMAS for example grows up to 25% more ice than the total change in volume

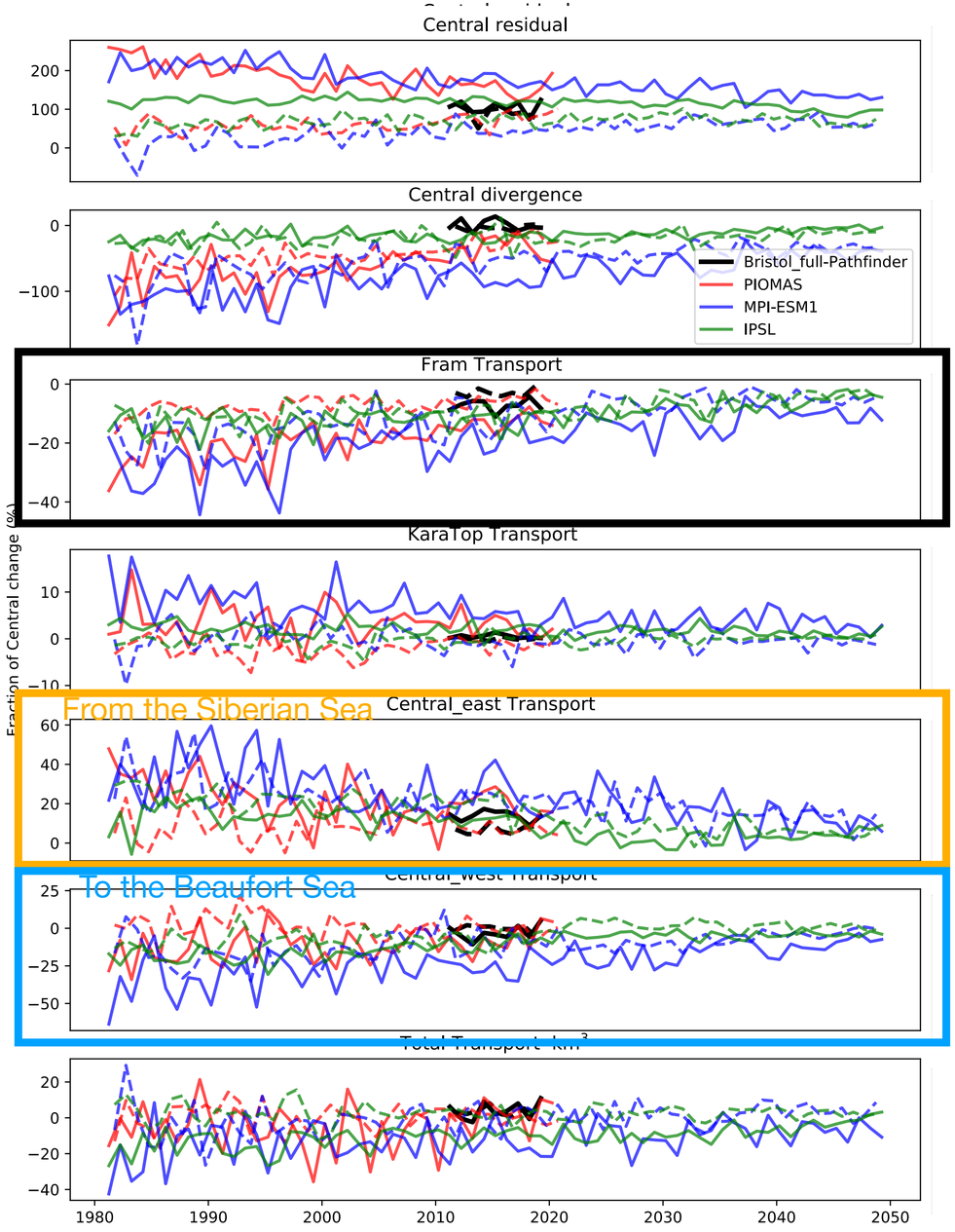
Seasonal Thermodynamic Growth as a fraction of total volume change



Focus on the Central Region

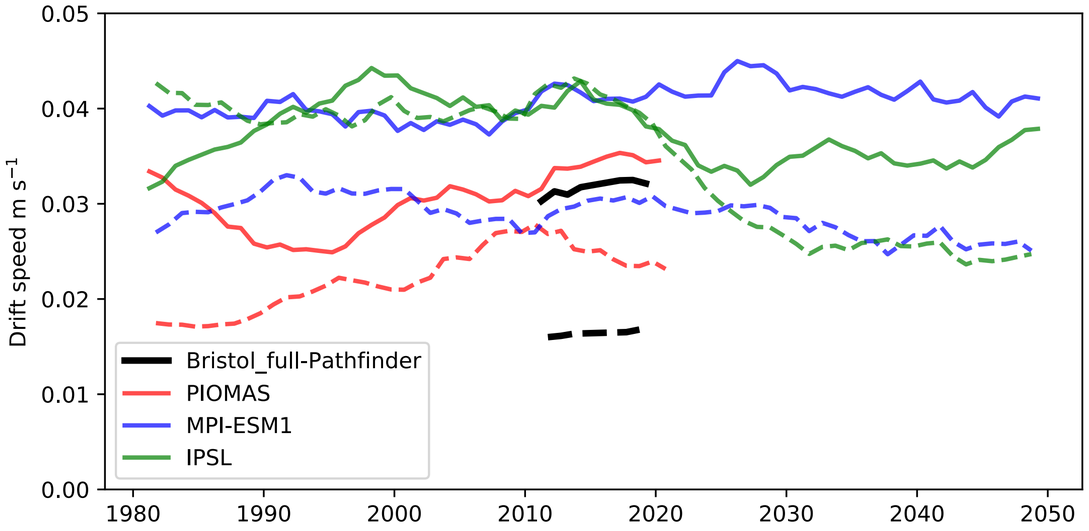
- In the 1980s MPI-ESM1 and PIOMAS suggest that 200% of the total central winter growth was in thermodynamics
- This was balanced by the divergence of thick ice and the net ice transport
- Ice is transported in from the Siberian Sea, and out into the Beaufort Sea and through the Fram Strait
- Further into the next century all dynamical terms reduce with all change in the Central region due to thermodynamics





Are the models correct?

- We can check the drift speeds
- There is no significant change in drift speed for all the models
- We will extend the observational record to compare divergence rates between models and observations
- If the models are to be believed, then there exists an ice volume stabilising ice thickness/divergence feedback.



Decadal average drift speed for growth (solid) and melt (dashed) seasons

What is this thickness/divergence feedback?

- Up to the present day, the central Arctic Ocean has grown more sea ice than is needed to replace the summer melt as ice is lost in divergence and transport
- INCREASED summer melt has caused THINNER sea ice
- Sea ice velocities have remained relatively stable, therefore:
  - THINNER sea ice loses LESS volume due to divergence and transport
- Thermodynamic ice growth has remained stable, particularly in the central region, therefore:
  - the seasonal cycle INCREASES as less sea ice is lost due to dynamics
- An INCREASED seasonal cycle allows for winter sea ice volume and extent to persist

Why has thermodynamic ice growth remained stable?